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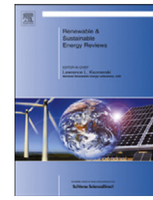

Energy savings in the combustion based process heating in industrial sector

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ABSTRACT

Energy efficiency and savings strategies in the combustion based industrial process heating has been reviewed comprehensively and presented in this paper. This work compiles latest literatures in terms of thesis, journal articles, conference proceedings, web materials, reports, books, handbooks on industrial process heating systems in the industrial sector. Different types of equipment used (i.e., recuperator, regenerators, heat wheels, heat pipes, economizers, etc.) and energy savings are reviewed in various industrial processes heating. Based on the review results, it is found that significant amounts of energy could be saved by using heat recovery system in the industrial process heating. By using recuperator up to 25% energy can be saved in the furnace. In the case of boiler, by using economizers 10% to 20% energy can be saved. Economic analysis shows that the payback period of recuperator and economizer are normally less than 2 years. It is also found that the payback period is lower when operating hour is comparatively high.

Contents

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1. Introduction

Energy is the key input and basic need in industrial facilities all over the world for development, economic growth, automation and modernization in the industrial sector [1,2]. However, global energy demands are increasing rapidly and this concern is addressed by international researchers on how to fulfill the future energy demand. The energy consumption will increase by 33% from 2010 to 2030 in the world [3]. Fig. 1 shows that world power demand rises from 145 billion MW in 2007 to 218 billion MW in 2035 (i.e., increases by 49%).

About 35% of world's total energy is used in industrial sectors [5]. It is also expected that the share of the industrial sector be augmented in the future. [6,7]. Changes in industrial activities and improvements of energy efficiency are tried to reduce the energy consumption but due to the impact of increase in economic activities, energy demand is increased in this sector [8]. Energy used in the industrial sector is more compare to any other end-use sector in the world. Demand of industrial energy depends on the regions and countries, economic activity and technological development, productions etc. Fig. 2 shows energy consumption in the industrial sector. Energy consumption increasing rate is projected for non-OECD countries and found averaging 1.8% per annum from 2007 to 2035. Table 1 shows the statistic for energy consumption in the industrial sector in different countries around the world.

Boiler and furnace are the most common equipment in the industrial sector. Major portion of energy consumption is owned by boiler and furnace in this sector. All major industries use fossil fuels to produce steam: food processing (57%), pulp and paper (81%), chemicals (42%), petroleum refining (23%), and primary metals (10%). Although industrial processes are very diverse, most of them are used steam system [23,24]. Industrial boilers consume about 37% of energy that is used in the industrial sector in the United States [25].

Climate change is an important environmental problem which potentially leads to rises in sea levels, loss of coastal land, and ecological shifts. A major cause of climate change is the emission of greenhouse gases [26]. Economic growth is closely linked to energy usage since higher economic growth leads to more energy consumption [27,28]. However, more energy production releases more emissions for environmental degradation (i.e., air pollution, climate change) [29,30]. The Intergovernmental Panel on Climate Change [31] reported that the most important existent environmental problem is the global warming. To save the earth by curbing global warming has become a common mission of all humanity [32]. In order to overcome this challenge, eco-efficiency approach is inducted to restrain emissions [33]. In 2004, world energy-related CO_2 emissions were 26.3 Gt [34]. The industrial sector contributes about 37% of the total emissions. Energy-related CO_2 emissions grew by an average of 1.5% in each year between 1971 and 2004, increasing by 1.6 times in about thirty years in the industrial sector [31]. Due to the importance of national energy plans, Jordan investigated and found electricity consumption and associated emissions in the industrial sector are predicted to rise by 63% in the year 2019 [13]. In Brazil about 81% of CO_2 emissions by the country's industrial sector come from energy use [10]. The combustion of fossil fuels contributes emissions of various gases such as CO_2, CO, NO_x, SO_2, trace of heavy metal contaminants and organic compounds. Kyoto Protocol (KP) in 1997 represented the first significant step for the reduction of emissions. The target is that the emissions in developed countries during the period (2008–2012) must be reduced by at least 5% below 1990 levels [35]. Since emissions mainly stem from burning of fossil fuels, reducing energy consumption seems to be the direct way of reducing the emissions [36]. Boiler and furnace are the main end energy users and fossil fuel (i.e., CNG, Diesel) is directly used in the industry. This is one of the major emission sources that directly burn fossil fuels.

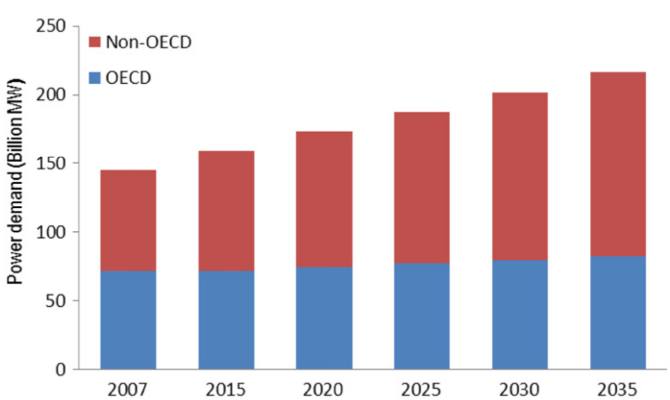

Fig. 1. World marketed power demand [4].

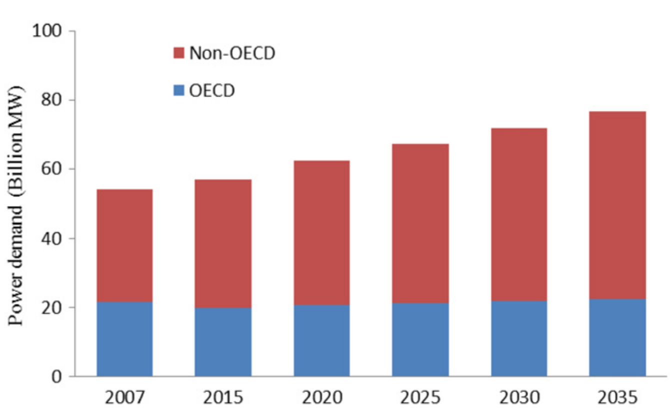

Fig. 2. World power demand in the industrial sector [4].

Table 1
Statistics of industrial energy use for some selected countries.

Country	Energy use (%)	Reference
Bangladesh	46	[9]
Brazil	41	[10]
China	70	[11]
Colombia	34	[12]
Germany	28	[12]
India	45	[5]
Jordan	31	[13]
Malaysia	48	[14]
Norway	40	[15]
Slovenia	52	[16]
South Africa	44	[17]
Sweden	38	[18]
Taiwan	51	[19]
Thailand	36	[20]
Turkey	35	[21]
US	33	[22]
World	35	[5]

Amount of emissions depends on fuel type, emission factor, percentage of excess air, burner efficiency, etc. Malaysia has to evaluate and exploit every feasible measure to reduce emission while maintaining its economic growth to meet this commitment of emission reduction. Thus, a comprehensive and representative industrial emission analysis is needed to assess the feasibility of numerous potential strategies to reduce emissions in Malaysia. Such analysis can be used to conduct comparative evaluations and be exploited as a policy making tool to achieve Malaysia's overall emission reduction commitment. Future industrial CO_2 emissions depend on changes in the technologies as well as industrial activities. It seems necessary to investigate future trends of energy consumption and emissions in industrial sector and their reduction potentials in order to make plans for a low carbon society. Sources of known energy have been exhausted rapidly leading to attempts to achieve an efficient and effective use of energy. It is also found that energy analysis is a vital means for energy planning, solving environmental issues and greenhouse gases reduction.

The objective of this study is to analyze different ways of energy savings in the process heating in industrial sector. The subsequent sections describe consecutively energy savings techniques, and energy efficiency policies and programs.

2. Process heating systems in industries

In the process heating systems, energy is transferred to the materials to be treated. There are direct and indirect heating systems. In the direct heating systems, heat is generated within the materials themself (i.e., microwave, controlled exothermic reaction etc.). In the indirect heating system, heat is transferred from heat sources to the materials by conduction, convection, radiation, or combination of these heat transfer mechanisms. In most processes, enclosures are used to isolate the heating processes from the outer environment. Fig. 3 shows the components of a system for process heating. The industrial process heating systems are categorized as follows [37,38]:

- Combustion based process heating
- Electric process heating
- Steam-based process heating

2.1. Combustion based process heating

In the combustion based process heating system, heat is produced during the combustion of fuel and transferred to the material to be treated. Common fuel used in the combustion based process heating are fossil and biomass fuels [37,38]. In the case of direct heating, combustion products (i.e., flue gases) are in contact with heat treated materials unlike the case of indirect heating where the gases are not in contact with the material (e.g., radiant panel) [37].

2.2. Electric process heating

In this case the electric current or electromagnetic field is used to produce heat to treat the materials. In the direct heating system, heat is generated within the work piece and that can be done by using the following tasks [38]:

(a) Passing the electric current through the materials
(b) Inducing electric current into the materials
(c) Exciting atoms in the materials by using the electromagnetic radiation

In the case of indirect heating system, heat is transferred into the heating element through conduction, convection, radiation or a combination of these mechanisms to the materials [37].

2.3. Steam-based process heating systems

In the steam-based heating systems, steam is used for supplying heat in the process. In the direct heating systems, stream is injected to the liquids or gases in the process. For the case of indirect heating systems, heat exchanger is used where steam is cooled and condensed in the tube and the heated tube delivers the heat to the liquids and gases. There are many advantages for stream process heating systems and it could be used for the varieties of by-product fuels [38].

2.4. Process heating energy sources

Energy source of process heating is one of the most important concerns. Major energy sources of process heating include electricity and fossil fuels. Type of the source applied for the system depends on different parameters (i.e., availability, cost, heating systems). Although the fuel is used to produce steam in boiler, it is represented as energy source in many processes in industry (i.e., heating of fluid, drying). Many other sources of energy also are put to use in industry (i.e., hot air, water). Renewable fuel sources (i.e., wood chips, bagasse) are less costly than conventional fuels. Fig. 4 shows the fuels used in several processes heating.

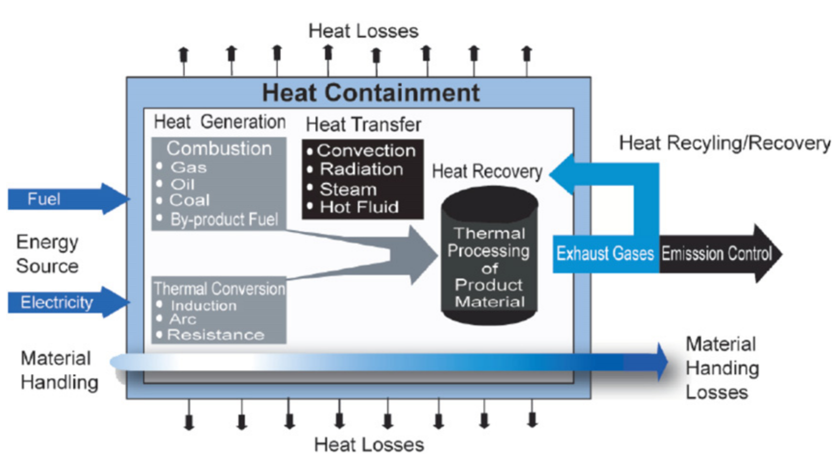

Fig. 3. Components of a process heating system [37].

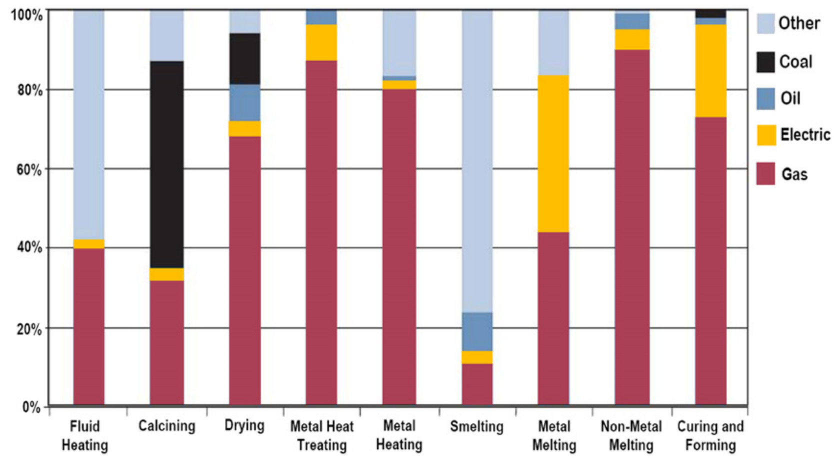

Fig. 4. Energy source of process heating in industries [37].

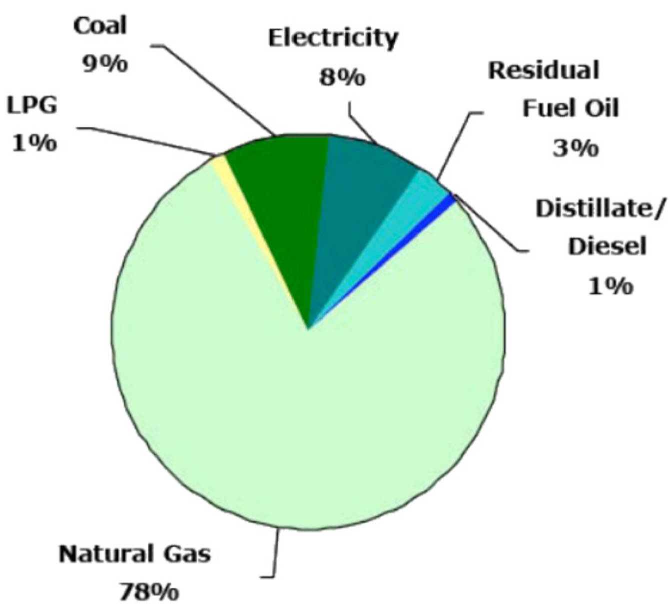

Fig. 5. Energy sources of the process heating [40].

2.5. *Energy uses in process heating*

The process heating technology could be modified by optimizing the install cost, operation and maintenance cost, control and quality of the product. The traditional energy sources are fossil fuels used for steam and hot water production. Electric heaters and boilers are popularly used for hot water, steam and direct process. The environmental drawback of the process heating can be solved by switching from fossil fuels to electric technologies as heaters. Process heating systems are the most common process in the industrial sector. Heating systems are essential in the industrial production. About 17% of total industrial energy is used in the process heating in the USA [39]. Fig. 5 shows that about 92% of the energy sources of process heating used directly include fossil fuel.

Energy demand in the process heating is increasing in the industrial sector. The expected increasing energy demand can be optimized by improving the efficiency of the system. Fig. 6 demonstrates the projected energy demand in process heating in the industrial sector by the year 2015.

In the chemical industries, approximately 307,962 GW h energy is used in the process heating that is about 32% of the total industrial sector. Fig. 6 shows that by the year 2015 energy consumption will be increased by 20% to nearly 366, 621 GW h of energy for process heating. Since about 92% of the energy consumed in process heating uses fossil fuels, energy efficiency measures as well as energy efficiency improvement projects should be performed for the future energy demand to reach a green world. Low efficiency equipment is used in the chemical that should be replaced by high efficiency equipment. More research and development should be carried out to improve the energy efficiency of equipment for the process heating. By using the concurrent advanced technologies and optimizing the operating condition about 5% to 25% reduction of energy used can be possible by the next 10 years [39].

3. Energy savings options in the process heating

Depending on the application of the process heating, the system size, configuration and operation practices vary throughout industrial sector. In the process heating system, there are many options to be implemented in for the industrial sector [37].

3.1. *Waste heat recovery*

In the industrial sector, steam is used for different purposes during the production in industrial plant. It provides heat in the chemical processing, food processing etc in the indutrial sector for different purposes. Boiler is used to produce stream that typically operates below the optimum efficiency. Heat (i.e., energy) losses in the steam generation and distribution systems is the result of poor and incompleate heating. Huge amount of waste heat are released trhough the flue gaeses of boiler, kiln, oven, furnace, etc. By recovering this waste heat, a huge amount of fuel can be saved [42,43]. There are many systems in the process heating where heat recovery system can be used. The major heat sources used for heat recovery purposes are condenser cooling water, process waste streams, condensate, boiler exhaust, furnace exhaust etc. [44]. Fig. 7 displays heat losses (i.e., possible heat recovery sources) from industrial heating processes. Fig. 8 shows a waste heat recovery flow diagram in the process heating.

3.2. *Waste heat recovery equipment*

There are various commercial heat recovery equipment to recover waste heat in different process heating systems in the industrial sector. This section describes the various heat recovery equipment and their application in the proces heating system.

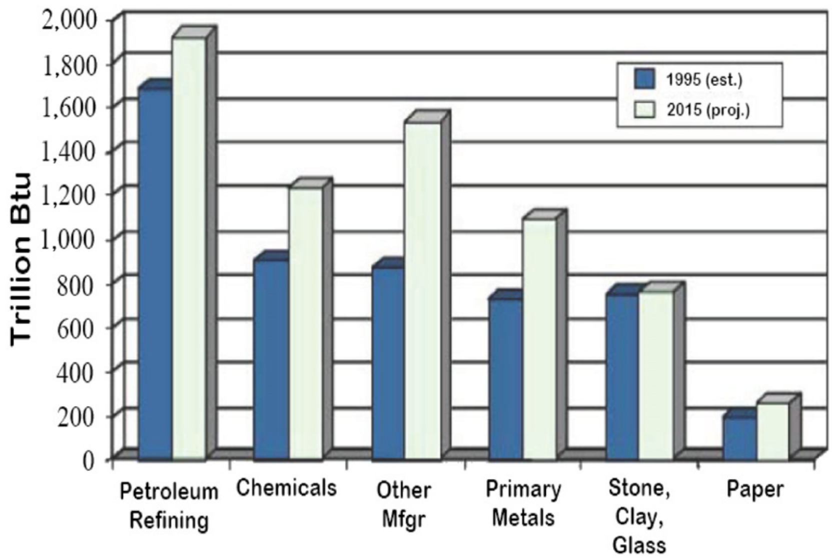

Fig. 6. Projected energy demand in process heating in the industrial sector [41].

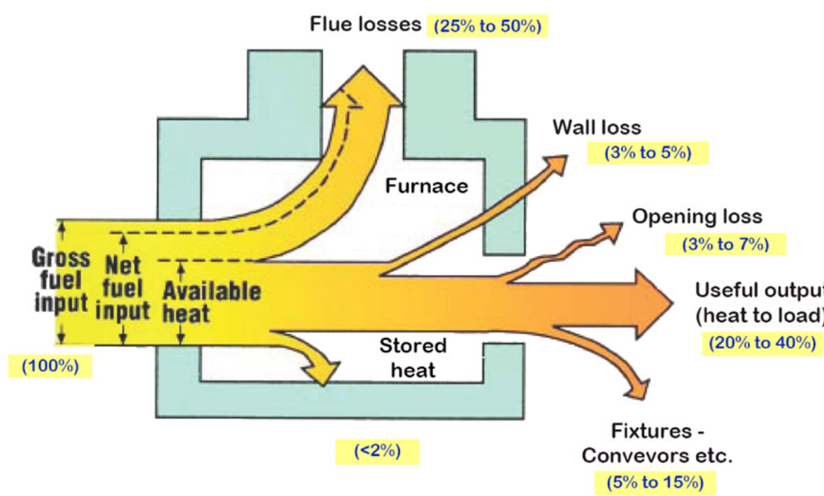

Fig. 7. Heat losses in the industrial heating processes [45,46].

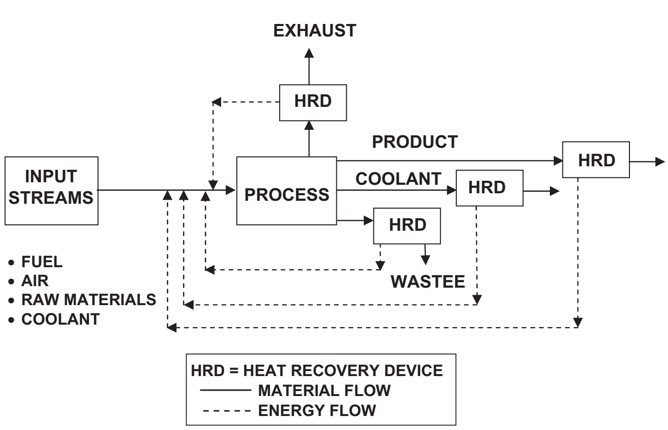

Fig. 8. Waste heat recovery flow diagram [47].

3.2.1. Recuperator

Recuperator is used for recovering waste heat from flue gases in the furnace or boiler. Heat is exchanged between the flue gase and air through by conduction through the metallic walls of the recuperator. Ducts are used to carry air to preheat before going to the combustion. A waste heat recovergy recuperator from flue gases is shown in Fig. 9. A furance is analyzed and found that the rate of heat recovered from flue gas is about 113.8 MJ/hr. Thus the fuel saving is 11,642.4 L/yr and fuel cost saving would be 17,463.6 RM/yr [42,48]. By assuming the cost of heat recovery system of the furnace to be RM 2400 [49], payback period is less than 2 months. If payback periods are less than one-third of the system life, it indicates that the implementation of system is very cost-effective [50]. Modern burners can withstand much higher combustion preheated air. Therefore it is possible to use heat recovery system to preheat the combustion air in the exit of the flue gas [51]. The input energy comes from the flue gas. Fuel consumption can be reduced about 25% by using the preheated air with high temperature of about 1327 °C [52].

Fuel combustion by using high temperature air would be one of the favorable technologies to reduce CO_2 as well as energy savings. Combustion with high heated air technologies was first introduced by British Gas and Hot Work Int in England. It is called Flameless Oxidation (FLOX) in Germany, Mild Combustion (MILD) in Italy and High-cycle Regenerative-combustion System (HRS) in Japan. By using HRS for the reciprocal firing and recovering heat from flue gas and achieving 20–40% energy savings [53–55]. But highly preheated air for traditional combustion results in high

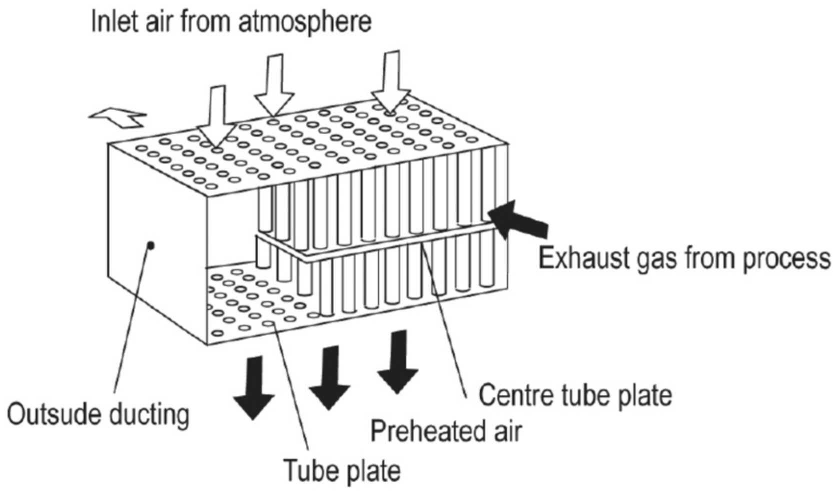

Fig. 9. Waste heat recovery recuperator [43].

NOx emissions. So, highly preheated air in traditional combustion is against of environmental issues as NOx emissions increases. To solve problem, new burner has been designed to reduce the NOx for high heated air combustion. The new combustion technologies have the following characteristics: (i) preheated air temperature is much higher than the mixture of self-ignition; (ii) high heated air and fuel entrain large amount of hot combustion product; (iii) slow combustion is sustained to reduce NOx [53,54,56,57].

3.2.1.1. Metallic radiator recuperator. The configuration of the metallic radiator recuperator consists of two concentric metal tube. Hot exhaust gas passes through the inner tube and the combustion air passes through external annulus to the inlet air toward the burner of the furnace. Hot gases and the combustion air exchange heat (i.e., combustion air gain heat from the hot flue gaes) and gives additional energy during the combustion. This aditional energy saves fuel that leads to less fuel consumption in the given furnace or boiler load. The fuel saving also decreases the combustion air and stack losses by lowering the stack gas temperatures [43].

3.2.1.2. Convective recuperator. In the convctive recuperator, the flue gases pass into the parallel tubes of small diameter. Air enters into the shells surrounding the tubes and flows over the tubes in the normal direction to the axes. Convective recuperator is more compact and more effective than radiation recuperator [43]. The multiple tubes make larger heat transfer area shown in Fig. 10.

3.2.1.3. Hybrid recuperator. In the case of hybrid recuperator, combinations of radiation and convective section have been designed to be implemented. The hybrid recuperator has a radiation section compared to the convective section. The effectiveness of heat transfer is very high in the hybrid recuperators and it is compact in size comapred to other sorts of recuperators [43].

3.2.1.4. Ceramic recuperator. In the case of heat recovery, the life of metal recuperators reduces linearly when temperature reaches more than 1100 °C. To overcome this limitation, ceramic recuperator has been developed. The ceramic recuperators allow in gas side of about 1550 °C with an air side of 815 °C. In the early days, ceramic recuperators were built with furnace cement. Nowadays, short silicon carbide tubes is used and the new designed systems are reported with the air preheat temperatures up to 700 °C [43].

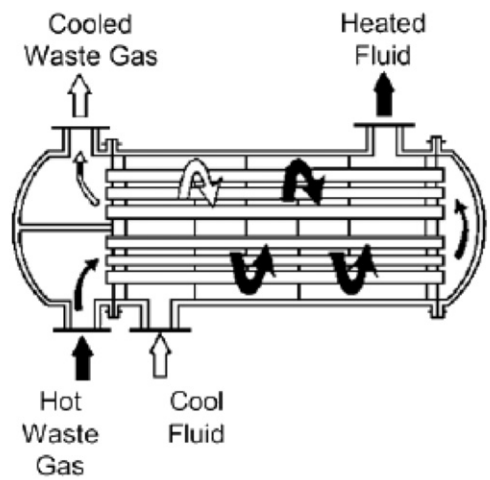

Fig. 10. Fluid flow in the convective recuperator [43].

3.2.2. Regenerators

Regenerator is used for the larger capacities in the glass and steel melting furnaces in industry. The important perameters are the size of the regenerator, reversal time, brick thickness, conductivity and heat storage ratio brick. Reversals time is one of the important aspects. Long period privides higher thermal storage but costly. Heat losses from the regenerator walls and gas as well as air leakage reduce the heat transfer [43].

3.2.3. Heat Wheels

In the case of low to medium temperature, heat wheel is used to recover the waste heat. The heat wheels is a porous disk fabricated by high heat capacity material that is rotated between two ducts of gasea (i.e., cold gas and hot gas). The sensible heat transfer is occured from hot gas and cold air with an overall efficiency of about 85%. Different types of heat wheel is used in the rotary regenerator where the cylinder rotates bewteen waste gas and air stream [43].

3.2.4. Heat pipes

Heat transfer performance of a heat pipe is very high (i.e., up to 100 times more) compared to the other conventional conductor. There is no moving part and as a result requires less maintenance

for the thermal energy absorbing and transferring system in the heat pipe. There are three basic elements in the heat pipe system: sealed container, capillary wick and working fluid. The main components of the capillary wick structure are the interior surface of the container tube and sealed under vacuum. Thermal energy applied to the external surface of the heat pipe is used to evaporate the working fluid instantaneously. The vapor fluid travels to the other end of the pipe and removes thermal energy to condense it into liquid again. This section of the the heat pipe is worked just like a condenser. The condensed liquid goes back to the evaporation region and evaporated [43,58]. This section of the the heat pipe operates just like an evaporator. Fig. 11 shows the heat pipe and the flow direction.

3.2.5. Economizers

A huge amount of energy is lost through the flue gas in the boiler. Since the minimum allowable stack gas temperature is 120 °C, huge amount of energy can be recovered from the flue gases. The economizer can be used to utilize the waste heat from the flue gas to pre-heat the feed water in the boiler. In every 220 °C reduction of flue gas temperature by using economizer, 1% reduction of boiler fuel consumption [59]. Fig. 12 shows an econimizer.

Recovered heat from flue gases can be improved the efficiency of the boiler. The recovered heat can be used to preheat the combustion air or feed water, and this will absolutely save the energy. A condensing economizer can be saved up to 20% of fuel by recovering the waste heat from flue gas. Condensing economizer has a wide range sizes, real energy and cost saver for industrial sector [60]. The cost of the economizer is about 90,000 RM [61]. In the economizer, there is no moving part that gives it very long life cycle and less maintenance cost. It is also found that the payback period is lower when operating hour is comparatively high. Payback period of condensing economizer is normally less than 2 years [60].

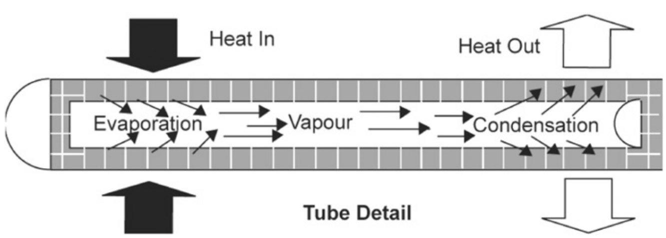

Fig. 11. Fluids flow, evaporation and condenser region of the heat pipe [43].

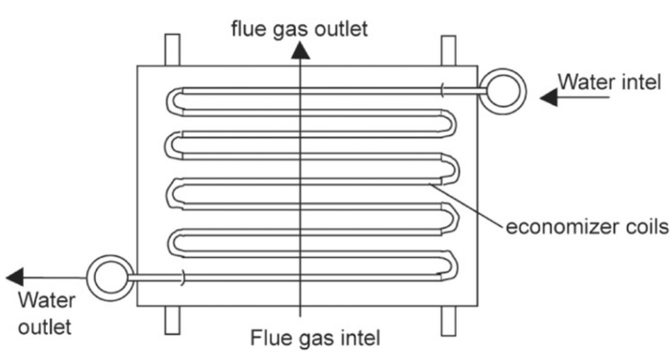

Fig. 12. Fluid flow in the economizer [43].

3.3. Waste heat quality and uses

Waste heat quality is an important perameter that determines if the heat can be economically recovered or not. Normally, higher temperatures means higher quality of waste heat as well as more cost effectiveness. It is noteworthy that the recovered heat can be used efficiently for the waste heat recovery (i.e., preheat combustion air, boiler feed water, process water). Fig. 13 shows waste heat uses in various systems in process heating. A cascade waste heat recovery system can be used to recover the maximum amount of heat from the gses [59]. Table 2 presents the possible sources of waste heat, quality and uses in the process heating.

3.4. Recovery potential of the heating processes

There are many sources where the waste heat can be recovered from the processes heating in the industry. Waste heat sources are clasified as high, medium and low temperatures of waste heat. Table 3 shows the high temperatures waste heat equipment sources in the industrial heating process equipment of the direct fuel fired processes. Table 4 displays the medium temperatures waste heat equipment sources in the industrial heating process equipment. Low temperature waste heat sources are more common and the temperature range 27 °C to 232 °C [59]. Usually the low temperature heat sources are not economical for extracting energy.

3.5. Waste heat quality and heat recovery equipment

The waste heat recovery system depends on the temperature and the heating process in the industrial sector. Depending on the

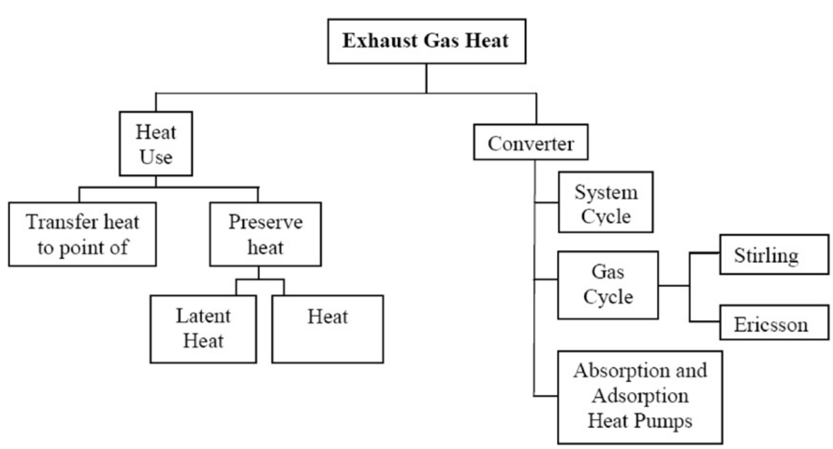

Fig. 13. Waste heat uses in the various system in the process heating [62].

temperature and heat sources, the suitable heat recovery should be selected. Table 5 shows the waste-heat recovery equipment for the various heat sources, temperature range and the usage of the waste heat in the industrial process heating systems. Depending on the industries and the process, the heating equipment also varies in the industrial process heating. Table 6 shows the various types of heat process, applications, euipment and industies in the process heating system.

Table 2
Waste heat source, quality and possible uses in the process heating [59].

No	Waste heat source	Quality	Possible use
1	Flue gases	Higher the temperture, greater the potential for heat recovery	To preheat feed water, combustion air and process water
2	Vapor streams	Higher the temperture, greater the potential for heat recovery	To preheat feed water and process water
3	Exterior surface of equipment	Low grade	Space heating, Air preheating
4	Cooling water	Low grade	To preheat feed water and process water
6	Products leaving the process	Quality depends upon temperature	Space heating or air preheating
7	Gaseous and liquid effluents of the process	Low grade	To preheat air

Table 3
High temperature waste heat sources in the industrial process heating [59].

Waste heat sources	Range of temperature (°C)
Furnace of nickel refining	1370–1650
Furnace of aluminum refining	650–760
Furnace of zinc refining	760–1100
Furnace of copper refining	760–815
Furnace of steel heating	925–1050
Furnace of copper reverberatory	900–1100
Furnace of open hearth	650–700
Kiln of cement	620–730
Furnace of glass melting	1000–1550
Hydrogen plants	650–1000
Solid waste incinerators	650–1000
Fume incinerators	650–1450

Table 4
Medium temperature waste heat sources in the industrial process heating [59].

Waste heat sources	Range of temperature (°C)
Steam boiler exhaust gases	230–480
Gas turbine exhaust gases	370–540
Reciprocating engine exhaust gases	315–600
Drying and baking ovens exhaust gases	230–600
Catalytic crackers	425–650
Cooling systems of annealing furnace	425–650

3.6. Benefits of waste heat recovery

The waste heat recovery systems provide various benefits in the process heating in the industrial sector. This is an important energy savings options in the various industrial process heating systems. The waste heat recovery systems can recover heat from sources of boilers, furnaces, ovens, dryers, heaters, air-cooled heat exchangers, kilns etc. Waste heat recovery systems reduce energy costs (i.e., decreases fuel, electricity use), greenhouse gas emissions, capacity and size of the plant thermal conversion equipment and improve productivity of the industrial processes. Benefits of the waste heat recovery are divided in two categories: direct benefits and indirect benefits.

3.6.1. Direct benefits of waste heat recoverygy

Waste heat remains unused that can be reused directly for useful and economic purposes. The quality of heat depends on how energy can be extracted out of total energy available rather than the absolute quantity. Recovery of heat also depends on temperature of the waste heat sources (i.e., flue gases in the case of boiler, furnace). In the case of boilers, kilns, ovens and furnaces, large quantity of hot flue gases is generated and this waste heat can be recovered. The recovery heat directly saves a huge amount of fossil fuel in the industrial sector [64]. These types of waste heat recovery have a direct effect on the process efficiency and reduce the utility consumption and costs as well as cost of the process heating system.

3.6.2. Indirect benefits of waste heat recoverygy

There are many indirect benefits of waste heat recovery in the industrial process heating (i.e., emissions and equipment size reduction). It also reduces various toxic combustible wastes (i.e., sour gas, oil sludge, acrylonitrile) that are released to the atmosphere. Hence the waste heat recovery reduces the environmental pollution levels [65–67]. Waste heat recovery also increases process heating efficiency and reduces fuel consumption, which leads to reduction in the plant size and flue gas produced;and as a result,reduces floor area and equipment sizes. Reduction in the equipment size leads to the decrease in the energy use of the auxiliary equipment (i.e., fans, pumps).

Table 5
Waste-heat recovery equipment for the various heat sources, temperature range and the usage of the waste heat [47].

Heat recovery device	Temp. range	Sources	Uses
Radiation recuperator	H	Boiler flue gas	Air preheating
Convective recuperator	M–H	Soaking/annealing oven, melting furnace, afterburners, reheat furnace	Air preheating
Furnace	H	Glass/steel-melting	Air preheating
Metallic heat wheel	L–M	Curing/ drying oven, boiler flue gas	Air preheat, space heating
Ceramic heat wheel	M–H	Large boiler flue gas	Air preheating
Passive regenerator	L–H	Drying/curing/baking oven	Air preheating, space heating
Finned-tube regenerator	L–M	Boiler flue gas	Make-up water preheating
Heat pipes	L–M	Drying/curing/baking oven,waste steam/air dryers/kilns/reverberator furnace	Air preheating, makeup water preheating, space heating
Gas/Steam turbines	M–H	High-pressure steam reduced for low-pressure application, waste steam	Generation of electrical or mechanical power

Table 6
Various types heat process, apllication, euipment and industies in the process heating system [63].

Process	Application	Equipment	Industry
Agglomeration sintering	Metals production	Various furnace types, kilns, microwave	Primary metals
Calcining	Lime calcining	Various furnace types	Cement, wallboard, pulp and paper manufacturing, primary metals
Curing and forming	Coating, polymer production, enameling	Various furnace types, ovens, kilns, lehrs, infrared, UV, electron beam, induction	Ceramics, stone, glass, primary metals, chemicals, plastics and rubber
Drying	Water and organic compound removal	Fuel-based dryers, infrared, resistance, microwave, radio-frequency	Stone, clay, petroleum refining, agricultural and food, pulp and paper, textile
Forming	Extrusion, molding	Various ovens and furnaces	Rubber, plastics, glass
Fluid heating	Food Preparation, Chemical Production, Reforming, Distillation, Cracking, Hydrotreating, Visbreaking	Various Furnace Types, Reactors, Resistance Heaters. Microwave, Infrared, Fuel-based Fluid Heaters, Immersion Heaters	Agricultural and food, chemical manufacturing, petroleum refining
Heating and melting	Casting, steelmaking, glass production	Fuel-based furnaces, kilns, reactors, direct arc, induction, plasma, resistance	Primary metals, glass
Heating and melting—low-temperature	Softening, liquefying, warming	Ovens, infrared, microwave, resistance	Plastics, rubber, food, chemicals
Heat treating	Hardening, annealing, tempering	Various fuel-based furnace types, ovens, kilns, lehrs, laser, resistance, induction, electron beam	Primary metals, fabricated metal products, glass, ceramics
Incineration/thermal oxidation	Waste handling/disposal	Incinerators, thermal oxidizers, resistance, plasma	Fabricated metals, food, plastics and rubber, chemicals
Metals reheating	Forging, rolling, extruding, annealing, galvanizing, coating, joining	Various furnace types, ovens, kilns, heaters, reactors, induction, infrared	Primary metals, fabricated metal products
Separating	Air separation, refining, chemical cracking	Distillation, membranes, filter presses	Chemicals
Smelting	Steelmaking and other metals (e.g., silver)	Various furnace types	Primary metals
Other heating processes	Food production	Various furnace types, ovens, reactors, and resistance heaters. microwave, steam, induction, infrared	Agricultural and food, glass, ceramics, plastics and rubber, chemicals

3.7. Waste heat recovery techniques

In the waste heat recovery systems, both sensible and latent heat recovery can be recoverable. In the case of flue gas heat recovery systems, condensing economizers can recover both sensible and latent heat and save energy from 10% to 20% [68]. Coil loop flue gas heat recovery systems also save energy from 2% to 4%. There are also direct and indirect latent and sensible heat recovery systems. In the direct heat recovery systems, water is sprayed directly into the flue gas stream and secondary heat exchanger is used to transfer the recovered heat into the stream from the process heating water. In the indirect waste heat recovery system, the waste heat is transferred into the process heating water. The indirect system is applicable where much higher temperature waste heat sources are available and no significant water treatment is required. In the waste heat recovery systems, electric fans are also used to push the flue gases into the heat recovery system (i.e., economizer, recuperator).

3.8. Economic evaluation of waste heat recovery system

Economic evaluation is the most important parameter in the development and usage of waste heat recovery system for a plant. Before developing a recovery system one should review the process of the plant. This review process helps in finding out the sources and uses of waste heat, plant condition for heat recovery, space availability, any constraint etc. After reviewing the process of the plant, the suitable heat recovery system could be selected. It is also of importance to do the economic analysis (i.e., investment, depreciation, payback period) in order to evaluate the selected waste heat recovery system for the plant.

4. Conclusion

Based on literatures, it has been found that huge amount of energy can be saved by using waste heat recovery system in the various industrial process heatings. The energy balance analysis makes it possible to improve the process optimization. In the flue gas waste heat recovery systems, condensing economizers can recover both sensible and latent heat and save energy from 10% to 20. By using recuperator in the furnace to preheat the combustion air about 25% energy can be saved. Waste heat recovery increases process heating efficiency and reduces fuel consumption, which leads to reduction in the plant size and the flue gas produced. The direct impact of waste heat recovery includes energy savings and its indirect impact is the reduction in pollution and emission. It is also of importance to do the economic analysis (i.e., investment, depreciation, payback period) in order to evaluate the selected waste heat recovery system for the plant. The payback period of recuperator and economizer are normally less than 2 years and it is decreased when the operating hour is increased. As payback periods are less than 2 years (less than one-third of the system life), it indicates that the implementation of system is very cost-effective.

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